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Future Monitoring of Charged Particle Energy Deposition Into the Upper Atmosphere and Comments on Possible Relationships Between Atmospheric Phenomena and Solar and/or Geomagnetic Activity

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The National Oceanic and Atmospheric Administration has been performing routine monitoring of Earth's atmosphere for several years utilizing the ITOS series of low-altitude, polar-orbiting weather satellites. A space environment monitoring package has been included in these satellites to perform measurements of a portion of Earth's charged particle environment. We describe briefly the charged particle observations proposed for the new low-altitude weather satellite TIROS N, which will provide the capability of routine monitoring of the instantaneous total energy deposition into the upper atmosphere by the precipitation of charged particles from higher altitudes. Such observations may be of use in future studies of the relationships between geomagnetic activity and atmospheric weather pattern developments. Estimates are given to assess the potential importance of this type of energy deposition. Discussion and examples are presented illustrating the importance of distinguishing between solar and geomagnetic activity as possible causative sources. Such differentiation is necessary because of the widely different spatial and time scales involved in the atmospheric energy input resulting from these various sources of activity. Examples also are given illustrating the importance of thoroughly investigating all physical mechanisms that may potentially link the lower atmosphere to the varying energy inputs at high altitudes.

I am happy to have this opportunity to describe and comment briefly on the type and usefulness of charged particle measurements to be performed on the proposed TIROS N environmental satellite program. These measurements, concerning the energy deposition in the upper atmosphere due to charged particles, should be of use in future considerations of atmospheric weather phenomena and their relationship to solar and/or geomagnetic activity. It should be noted that the TIROS N environmental satellite program has not yet been approved and is presently under review by the Office of Management and Budget.

Figure 1 is a schematic showing the orbit of the TIROS N spacecraft. The proposed orbit is circular at an altitude of 1700 km with a 103° inclination, which maintains it in a Sun-synchronous attitude. A currently operating real-time data transmission system is illustrated in the figure. Data are available at the Space Environment Laboratory in near real time and are immediately placed into an operational real-time data base made up of data collected throughout the solar/terrestrial environment. In addition, the satellite data recorded throughout the orbit are available on a longer time basis for research and archiving.

The satellite is oriented at high latitudes so that the charged-particle detectors are able to obtain a measure of the particle pitch angle distri-

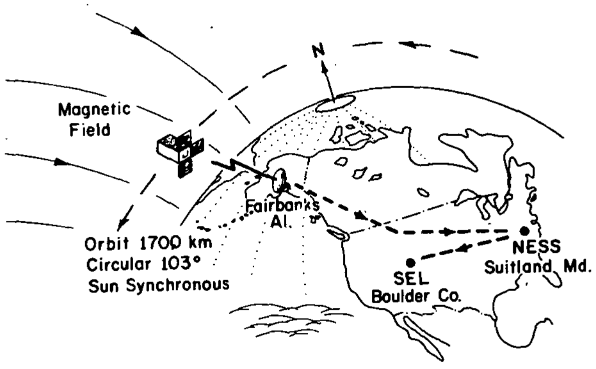

FIGURE 1.—TIROS N spacecraft orbit. It will be launched in mid 1977. Followup operational spacecraft will be launched at 1- to 2-yr intervals. (NESS = National Environmental Satellite Service; SEL = Space Environment Laboratory.)

bution at these altitudes. A set of detectors looks normal to the field line, thereby measuring particles with a local pitch angle of 90°. An additional set of detectors is oriented to look upward nearly along the field line, thereby measuring particles whose local pitch angles are very small. It is these latter particles that precipitate directly into the upper atmosphere and are directly responsible for such phenomena as polar cap absorption, auroral displays, and possibly phenomena in the lower atmosphere. The charged-particle observations aboard TIROS N therefore allow the measurement of the total instantaneous energy deposition to the local atmosphere due to charged particles.

Figure 2 shows the energy range to be covered. This range extends from several hundred to greater than 10^9 eV. A variety of detectors (thin scintillators, solid-state detectors, and Cerenkov detectors) will be used to cover this energy range and will be sized to measure energy inputs greater than or equal to 10^{-2} ergs/cm^2 · s. Details of how the various energy ranges will be covered and details of instrument design can be obtained from the Space Environment Laboratory, Boulder, Colo.

Because we are proposing to monitor on a routine basis the energy deposition at the top of the atmosphere due to charged particles, let us try to assess its importance. In figure 3, we show a photograph of an aurora obtained from the DOD Data Acquisition and Processing Program (DAPP) satellite on January 11, 1973. Included in the figure is a summary of estimates of energy deposited by such an aurora into the upper atmosphere. The upper portion of the auroral photograph is in the dawn hemisphere, the broad diffused band near the right-hand portion is near local midnight, and the two line structures extending to the lower left of the photograph are in the local evening sector. The aurora also can be seen over the polar cap alined in the noon-midnight direction.

The area of the photograph is approximately 1.4×10^7 km^2, with approximately 20 percent of the area covered with auroral glow. A modest energy influx during an aurora is approximately 4 ergs/cm^2 · s. This value yields a total energy influx in figure 3 of approximately 10^{17} ergs/s = 10^{10} W.

We also can estimate the total power dissipation through joule heating due to ionospheric current flow at the 115-km level. Using an ionospheric integrated Pederson conductivity for moderate levels of disturbance of

$$\Sigma\sigma \sim 20 \text{ mhos/m}$$

and a nominal potential difference of about 0.015 V/m, a power dissipation of approximately 4.5×10^{-3} W is obtained for a column of 1 m^2 cross section. If this current is flowing within the auroral glow shown in figure 3, a total power dissipation of approximately 10^{10} W exists.

Using these estimates, considering the possibility of current along geomagnetic field lines, and estimating the volume energy deposition rates due to auroral particle precipitation, heating rates of more than 1000 K per day (1.4×10^{-2} K/s) result if the assumption is made that this energy heats the neutral atmosphere at these altitudes (110 to 125 km). Thus it is apparent from such estimates that the energy deposition into the atmosphere at altitudes above 110 km due to magnetospheric processes exceeds that due to solar energy flux at high geomagnetic latitudes. This should not only cause considerable heating of the high-altitude neutral atmosphere but may also generate significant neutral winds at these altitudes.

The preceding estimates were concerned with intense particle precipitation due primarily to geomagnetic processes. Let us consider an example of such effects due to solar flare activity. In con-

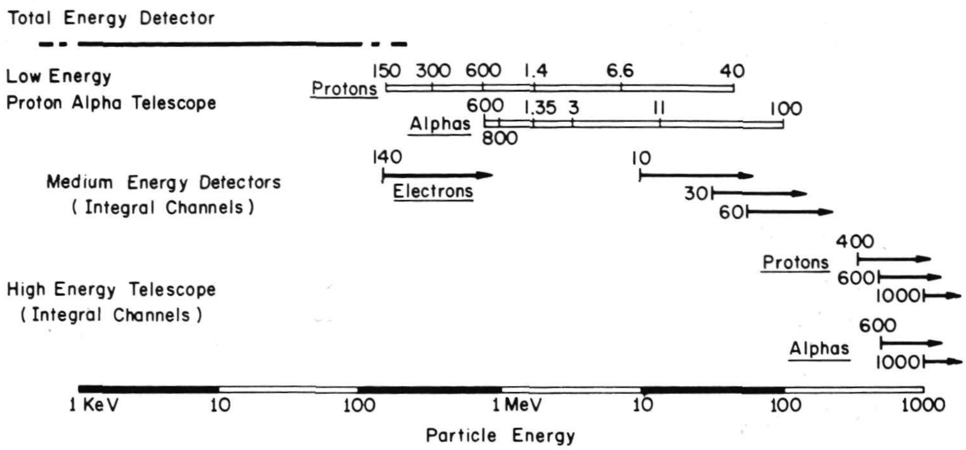

FIGURE 2.—Energy coverage of proposed TIROS N space environment monitor.

trast with auroral particle precipitation, which is confined to a relatively narrow latitude band ($\leqslant 10°$) and may last for hours, particles released from a solar flare impinge on Earth's atmosphere over the entire polar cap region and last for several days. Thus the time scales for the energy input are longer and the atmospheric spatial scales over which the energy input occurs are greater for solar flare particles than for auroral processes. In contrast, however, the frequency of occurrence is greater for auroras than it is for particle-emitting solar flares.

We shall use the solar flare activity occurring in August 1972 to obtain an estimate of energy dissipation into the upper atmosphere over one polar cap. For the several days during which intense solar particle activity occurred during the August 1972 solar exents, a peak energy dissipation rate into the polar cap of approximately 2 ergs/cm^2 · s occurred for a ½-hr period. For the remaining several days of this solar activity, the energy dissipation rate due to flare-associated particles was less than approximately 0.2 ergs/cm^2 · s. Using a polar cap area of approximately 2.5×10^{17} cm^2 yields a peak energy dissipation rate over one polar cap of 5×10^{17} ergs/s = 5×10^{10} W. Using the ½-hr time interval for the event peak yields a total peak power of 3×10^7 kW hours deposited in an altitude range of 40 to 70 km. This could give a mean heating of the order of 1° to 3° over the altitude range of deposition.

We see evidence for significant energy deposi-

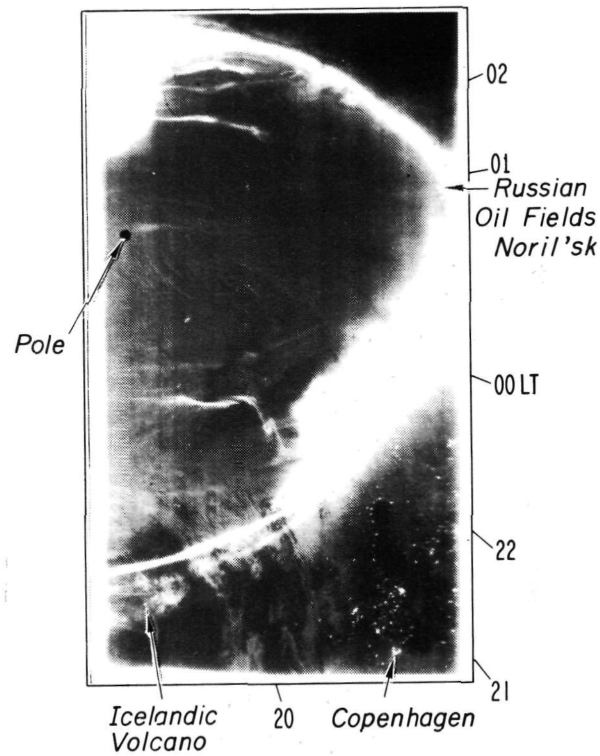

FIGURE 3.—Aurora obtained from the Data Acquisition and Processing Program (DAPP) satellite on January 11, 1973. The estimated area of the aurora in the satellite picture is approximately 2.8×10^6 km^2. For a commonly occurring "moderate" aurora, which will last for several hours, the particle energy deposition is approximately 4.0 ergs/cm^2 . s, or a total power input of approximately 1.1×10^{10} W. The ohmic losses due to the Pedersen currents flowing at 110 to 120 km may be approximately 1×10^{10} W. If these processes heat the neutral atmosphere at 115 km, the resultant heating rate would be greater than 1000 K/day.

tion in Earth's upper atmosphere due, in this case, to particles emitted during a solar flare. Consequently, the routine observations of such energy depositions may play an important role in delineating mechanisms responsible for correlations between atmospheric weather and solar and/or geomagnetic activity.

In such correlations, it is extremely important to distinguish between solar activity and geomagnetic activity because of the vast differences in the spatial and temporal scales of the energy input into Earth's upper atmosphere. At this conference we are hearing of potential atmospheric responses ranging in time from several days (corresponding to the development of atmospheric storm systems) to 11 to 22 yr (corresponding to correlations with the solar cycle) and on to many millenia (corresponding to hypotheses concerned with glacial advances and recessions). Similarly, the spatial scales in the atmosphere vary from more or less localized continental storm systems to global climatic changes.

If causes related to variations in the solar terrestrial realm are sought, it is important that the necessary energy input be compatible with the atmospheric phenomena being studied. For example, any variation in the electromagnetic emission of the Sun (X-ray, UV, visible, IR, and radio energy) produces a global variation throughout Earth's sunlit hemisphere. Consequently, slight

TABLE 1.—*Spatial and Temporal Considerations of Energy Inputs to Atmosphere Associated With Solar and Geomagnetic Activity*

Extra-atmospheric activity	Time scale	Atmospheric spatial scale[a]	Potential atmospheric effects
Solar:			
Overall change in electromagnetic emission from the Sun (includes possible changes in solar constant)	Millennia(?)	Global, direct	Long-term worldwide climatic changes. Glacial advances and recessions.
Overall change in emitted solar wind	Millennia(?)	Global, indirect	Long-term worldwide climatic changes. Glacial advances and recessions.
Number of sunspots[b]	Solar cycle 11 to 22 yr	Global, direct, indirect	Shorter term climatic changes, for example, the 20- to 22-yr cycle of U.S. High Plains droughts. Motion of atmospheric jet stream.
Solar flare particle emission	Days	Polar regions, direct	Atmospheric storm system development. Isolated, unique atmospheric phenomena.
Solar flare shock wave	Hours	Global, indirect	Atmospheric storm system development. Isolated, unique atmospheric phenomena.
Geomagnetic:			
Aurora (precipitated particles and currents in substorms)	Hours	Narrow latitude band ($\leqslant 10°$) at high latitudes. Night side. Direct.	Atmospheric storm system development. Isolated, unique atmospheric phenomena.
Magnetic storms	Days	Wide latitude band at mid-latitudes. Global. Direct.	Atmospheric storm system development. Isolated, unique atmospheric phenomena.

[a] Direct = energy from given phenomena applied directly to the atmosphere. Indirect = energy from given phenomena applied indirectly to the atmosphere; for example, solar wind energy applied through magnetospheric coupling to the atmosphere.

[b] As indication of overall solar activity.

changes in the solar constant over long periods of time might provide a more appropriate mechanism to explain long-term global climatic variations.

Table 1 is a rough attempt to block out atmospheric spatial and temporal scale sizes associated with a few examples of solar and geomagnetic activity. It is not intended to imply cause and effect but simply to emphasize the spatial and temporal scales of atmospheric energy input associated with various types of solar and geomagnetic activity.

Finally, in attempting to understand many of the correlations being presented, it is necessary to examine all possible mechanisms that may conceivably provide a connection between the lower atmosphere ($\leqslant$10 km) and solar and geomagnetic activity. For example, it has been long known that atmospheric turbulence is capable of producing upward-traveling acoustic gravity waves that can carry significant amounts of energy into the high altitude ($\geqslant$100 km) regions. If this occurs under conditions of marginal stability in the geomagnetic particle population, these waves could conceivably create turbulence in the ionosphere at the foot of the geomagnetic field lines and initiate instabilities leading to enhanced particle precipitation. Note that such possibilities are maximized when enhanced geomagnetic activity is imminent and when large atmospheric storm systems are developing, and would naturally lead to positive correlations under conditions set forth in many reported studies. Ionospheric effects of this type apparently have been observed (Bauer, 1957, 1958; Davies and Jones, 1971, 1973) and, in one case, interpreted as upward/propagating acoustic gravity waves setting the ionosphere at 200-km altitude into large-scale vertical oscillations having periods of several minutes (Davies and Jones, 1973). Mechanisms such as this should be identified, assessed in importance, and clearly separated in correlations of atmospheric weather development with solar and/or geomagnetic activity. Only then will the reality of solar activity and geomagnetic effects on Earth's weather and climate be established.

ACKNOWLEDGMENTS

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